A Reassessment of the Expanded EPA/ASCE National BMP Database

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ABSTRACT

The USEPA/ASCE National BMP Database has grown significantly since the first evaluation of BMP performance data in the database was completed in 2000. The project team is currently performing a re-evaluation of the data contained in the database to assess the overall performance of BMPs as well as compare BMP design attributes to performance. Although this analysis has not been fully completed, several initial results are presented in this paper.

The evaluations include the assessment of various BMP types as categorized in the database with regards to their ability to reduce runoff volumes as well as improve effluent quality. Certain BMP types may reduce the volume of runoff through evapotranspiration and/or infiltration, as opposed to BMPs that are more "sealed," such as wet ponds, wetlands, and vaults. Runoff reductions directly reduce pollutant loading as does improved effluent quality. On average, dry detention basins were found to reduce runoff volumes by an average of 30% (comparison of inflow to outflow), while biofilters reduced volumes by almost 40%. As expected, wet ponds, wetlands, and hydrodynamic devices, and retention ponds show little or no runoff volume reductions. BMP types vary with regards to effluent quality that is achieved. BMPs such as wet ponds and wetlands appear to achieve lower concentrations in effluent quality than other BMPs such as detention ponds (dry) and hydrodynamic devices. These differences vary with pollutant type. With more data available, analyses of BMP design versus performance show statistically valid results. For example, a relationship (ratio) between the treatment volume of retention ponds (with wet pools) versus the average size storm event volume monitored has been established, showing that those with a ratio of 1 or greater have been observed to achieve significantly better effluent quality.

This paper also briefly overviews the Urban Stormwater BMP Performance Monitoring ("Manual") (Strecker, et. al., 2002) that was developed by integrating experience gleaned from field monitoring activities conducted by members of ASCE's Urban Water Resource Research Council and through the development of the ASCE/EPA National Stormwater Best Management Practices Database. The Manual is intended to help achieve stormwater BMP monitoring project goals through the collection of more useful and representative rainfall, flow, and water quality information.

INTRODUCTION

The USEPA (Environmental Protection Agency)/ASCE (American Society of Civil Engineers) National Stormwater BMP (Best Management Practice) Database has been under development since 1994, under a USEPA grant project with the Urban Water Resources Research Council (UWRRC) of ASCE (Urbonas, 1994). The project has included the development of recommended protocols for BMP performance (Urbonas, 1994 and Strecker 1994), a compilation of existing BMP information and loading of suitable data into a specially designed database (www.bmpdatabase.org), and an initial assessment of the results of the analyses of the database (Strecker et. al., 2001). In addition a detailed guidance document on BMP monitoring has been developed, entitled "Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements" (available for download at: www.bmpdatabase.org).

Many studies have assessed the ability of stormwater treatment BMPs (e.g., wet ponds, grass swales, stormwater wetlands, sand filters, dry detention, etc.) to reduce pollutant concentrations and loadings in stormwater. Although some of these monitoring projects conducted to date have done an excellent job of describing the effectiveness of specific BMPs and BMP systems, there has been a lack of standards and protocols for conducting BMP assessment and monitoring work. These problems become readily apparent for persons seeking to summarize the information gathered from a number of individual BMP evaluations. Inconsistent study methods, lack of associated design information, and varying reporting protocols make wide-scale assessments difficult, if not impossible. (Strecker et al. 2001; Urbonas 1994) For example, individual studies often include the analysis of different constituents and utilize different methods for data collection and analysis, as well as report varying degrees of information on BMP design and flow characteristics. The differences in monitoring strategies and data evaluation alone contribute significantly to the wide ranges of BMP "efficiency" (typically percentage removal) that has been reported in literature to date.

Municipal separate storm sewer system owners and operators, industries, and transportation agencies need to identify effective BMPs for improving stormwater runoff water quality. Because of the current state of the practice, however, very little sound scientific data are available for making decisions about which structural and non-structural management practices function most effectively under what conditions and designs; and, within a specific category of BMPs, to what degree design and environmental static and state variables directly affect BMP performance. The protocols developed under this project and the Urban Stormwater BMP Performance Monitoring guidance addresses this need by helping to establish a standard basis for collecting water quality, flow, and precipitation data as part of a BMP monitoring program. The collection, storage, and analysis of this data will ultimately improve BMP selection and design.

One of the major findings of the EPA/ASCE BMP Database efforts to date has been that BMP pollutant removal performance for most pollutants is believed best assessed by the following: (Strecker et. al., 2001):

- How much stormwater runoff is prevented? (Hydrological Source Control)
- How much of the runoff that occurs is treated by the BMP or not?
- Of the runoff treated, what is the effluent quality?

For some pollutants, the amount of material captured could also be important, as well as how the BMP mitigates temperature and/or flow changes. Percent removal of pollutants is a highly problematic method for assessing performance and has resulted in some significant errors in BMP performance reporting (Strecker, et. al., 2001).

Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements (available for download at: www.bmpdatabase.org) is intended to improve the state of the practice by providing recommended methods for meeting the EPA/ASCE BMP Database protocols and standards (Urbonas 1994) for collecting, storing, analyzing, and reporting BMP monitoring data that will lead to better understanding of the function, efficiency, and design of urban stormwater BMPs. Furthermore, it provides insight into and guidance for strategies, approaches, and techniques that are appropriate and useful for monitoring BMPs. The overall focus of the document is on the collection, reporting, and analysis of water quantity and quality measurements for quantitative BMP performance studies. It does not address, in detail, sediment sampling methods and techniques, biological assessment, monitoring of receiving waters, monitoring of groundwater, streambank erosion, channel instability, channel morphology, or other activities that in many circumstances may be as, or more, useful for measuring and monitoring water quality for assessing BMP performance under some circumstances.

RE-EVALUATION OF THE NATIONAL BMP DATABASE

The project team is completing a detailed assessment of the expanded database. Table 1 presents an overview of the BMPs currently in the database, including the number of data records for each BMP type. New BMP information is being provided to the database team at about a rate of 15 to 20 studies per year. These are studies that meet the protocols established for BMP monitoring and reporting. The 170 studies now in the database compares with the total of just over 60 BMP studies in the database during the initial evaluation.

Each study has again been analyzed in a consistent manner as described in Strecker, et. al. 2001) and on the project web site. The data being produced includes lognormal distribution based summary statistics, comparisons of influent and effluent water quality through parametric and non-parametric hypothesis tests, and a large number of other summary statistics. In this evaluation, the project team has been investigating the effects of BMPs on hydrology and effluent quality. The project team is currently working on evaluation of the design attributes versus BMP performance, which will be highlighted in more detailed at in the presentation.

Table 1. Number of BMPs and Data Records (events or event mean concentrations) in the National BMP Database as of 11/01/02

BMP Type	# of BMPs in Category with Design Information	Precipitation Records for BMP type	Flow Records for BMP Type	Water Quality Records for BMP Type
Detention Basins	24	129	229	4209
Grass Filter Strips	32	227	385	6,251
Media Filter	30	187	327	6,144
Porous Pavement	5	5	5	55
Retention Pond	33	378	817	14,293
Percolation Trench and Dry Well	1	3	3	21
Wetland Channel and Swale	14	53	113	1,241
Wetland Basin	15	221	681	7,320
Hydrodynamic Devices	16	169	309	6,186
Total	170	1372	2,869	45,720

Hydrology Evaluation

One of the goals of the data base was to provide better information on the effects of BMPs on hydrology and whether some BMPs may have some benefits over others in terms of reducing volume of runoff (Hydrological Source Control-HSC). For example, one would expect that a wet pond might not significantly decrease the volume of runoff, but a biofilter might, given the contact with more frequently drier soils and resulting evapotranspiration and/or infiltration. Accurately measuring flow during storm conditions is very difficult (EPA, 2002). In a field test of over 20 different flow measurement technologies and approaches, FHWA (2001) found that flow measurements can be upwards of 50% or more off of the expected true flow. Therefore assessments of the database will likely show some variability in flow changes due to measurement errors.

Figure 1 presents plots of inflow versus outflow for Biofilters (Swales and filter strips), Detention Basins (dry ponds), Retention Ponds (wet ponds) and Wetland Basins. Biofilters showed an average of 20% less volume of runoff on a storm-by-storm basis and were consistently lower for almost all storm events. The other BMPs showed a large scatter, but generally showed an increase in runoff volumes. While showing an increase on a storm-by-storm basis, dry ponds tended to have many more storms that were lower in outflow.

Table 2, presents the results of removing the smaller more insignificant storms from the analyses (storms resulting in flows less than 0.2 watershed inches removed). The term "watershed inches" refers to an area-normalized volume (the total volume divided by the total watershed area). From these analyses, it is apparent that detention basins (dry ponds) and biofilters (vegetated swales, overland flow, etc.) appear to contribute significantly to volume reductions, even though they were likely not specifically designed to do so. One needs to note that although in our protocols we ask for the total storm volume of the influent and effluent over the entire event, it is possible that some studies may have cut-off effluent sampling before the BMP returned to pre-storm conditions. Based upon the recommended criteria above for assessing BMP performance, it appears that there is a basis for factoring in volume and resulting pollutant load reductions into BMP performance. This has significant implications for Total Maximum Daily Loads (TMDLs) implementation planning and other stormwater management planning. It is also expected that as BMPs that are specifically designed to reduce runoff volumes (e.g., lower impact development, etc.) are tested and information added into the database, that these results will improve.

Water Quality Performance

The analysis of water quality performance data of the BMPs that we are being conducted by the authors performing is comprised of three levels: 1) a comprehensive evaluation of effluent versus influent water quality; 2), comparisons of effluent quality amongst BMP types; and 3) comparisons of performance versus design attributes for BMP types and individual BMPs. Even with the increase in data in the database since the last evaluation, the total number of BMPs in any one category is still small as compared to the number of design parameters that can be potentially investigated. The approach that the team has taken is to develop groupings of BMPs by Design Factors. That is, our approach has been to develop categories of design parameters that are expected to affect performance, group BMPs into those that meet all or most of the factors (e.g., length to width ratios; volume of facility as compared to average storm inflow, etc.) and then explore if a difference in performance can be established and potentially explained by these assessments of these grouped design factors.

Figure 2 presents plots shows a box plot of the fractions of reported Total Suspended Solids (TSS) concentrations removed and the box plots of effluent quality of BMP types. As has been found previously (Strecker et. al., 2001), the effluent quality is much less variable than fraction removed. It appears that percent removal is more or less just a function of inflow concentration. Recent analysis of the expanded database shows that effluent quality can be assumed to be different among different BMP types. It appears that Retention Ponds (wet ponds) and Wetlands can achieve lower concentrations of TSS than other BMPs, while hydrodynamic devices were the lowest performers (higher effluent concentrations) on average. Similar results have been found for other constituents with some variations. One should note (discussed below) that there are serious questions regarding the validity of TSS as an accurate measure of suspended solids. However, the problems with TSS methods are likely not large with effluent quality as most of the potentially missed larger fractions would likely have been removed if the BMP is "working" at all.

Figure 3 shows the result for comparing Total Phosphorus and Total Copper concentrations for the same BMP categories. Wetlands and wet ponds are more consistent performers, while the other BMPs vary with regards to effluent quality results. The lowest effluent quality achieved for Phosphorus is on the order of 50 to 60 ug/l. This contrasts with some water quality efforts where the ultimate phosphorus goal has been selected to be in the range of 10 to 20 ug/l and then showing achievement of such goals by misapplication of percent removal approaches.

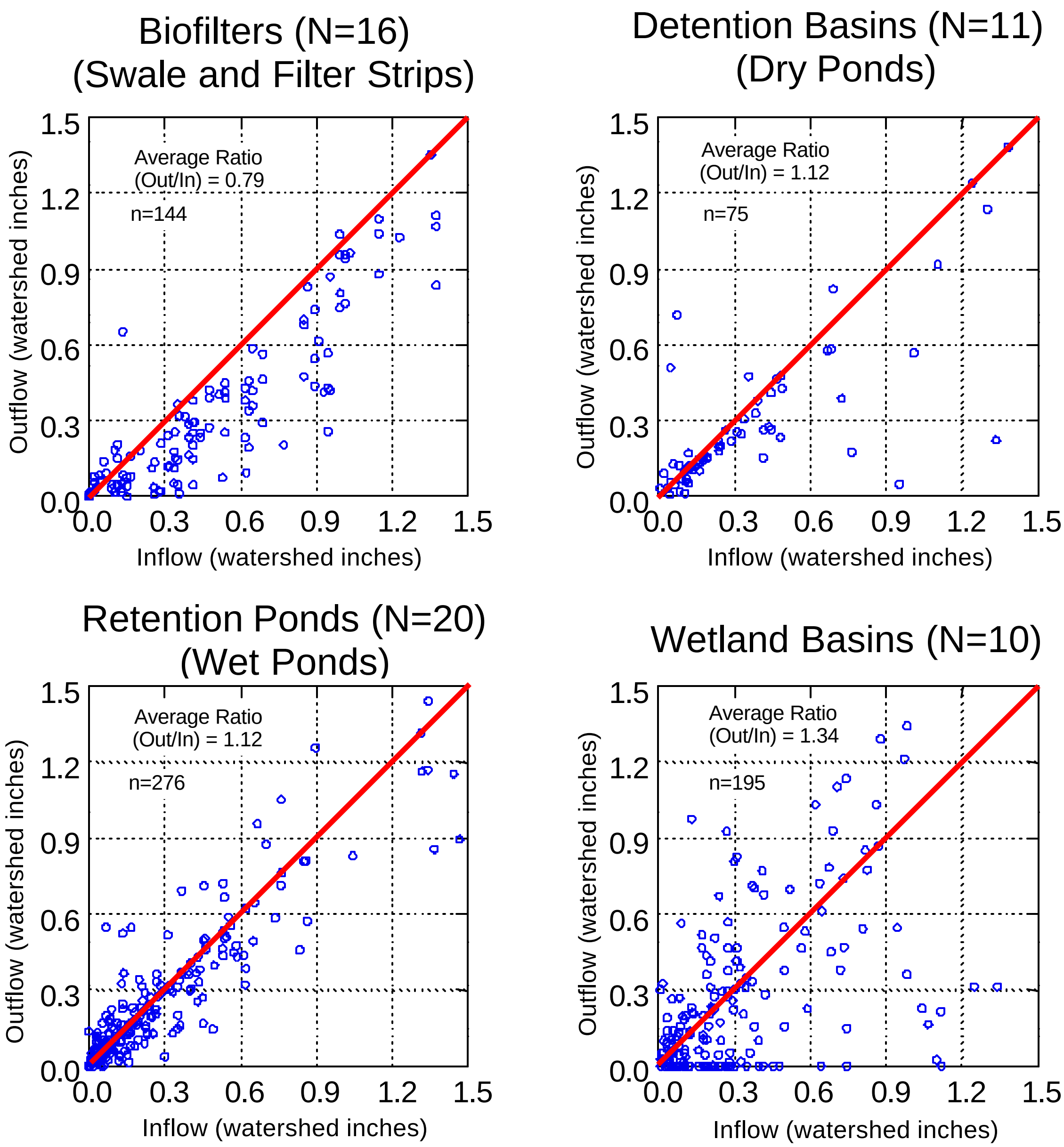

Figure 1. Comparison of Individual Storm Inflow and Outflow Volumes for Indicated BMPs (N= number of BMPs included; n= number of storm events)

As mentioned above, we are exploring individual BMP designs (sizing, etc.) relative to performance. Some initial results of the expanded database have been encouraging. For example, the previous effort during the initial work was not able to statistically find a potential relationship between performance of retention ponds and wetlands and their treatment volume relative to measured storm events. Figure 4 shows a scatter plot of Retention Ponds (with a permanent pool) effluent quality versus the ratio of the treatment volume to mean monitored storm event volume, and a box plot of Retention Pond mean effluent quality for sites with ratio less than one and greater than one ratio of the treatment volume to mean monitored storm event volume. The plots clearly demonstrate that at those sites where the treatment volume was greater than the average size storm event monitored, the effluent quality was significantly lower. In addition, the variability of effluent quality for the larger retention ponds was lower. These results are expected, but it is one of the first times that they have been demonstrated statistically.

Table 2. Ratio of Mean Monitored Storm Event Outflow to Inflow for Storms Greater than 0.2 watershed inches.

BMP Type	Mean Monitored Outflow/Mean Monitored Inflow for Events Where Inflow is Greater Than or Equal to 0.2 Watershed Inches
Detention Basins	**0.70**
Biofilters	**0.62**
Media Filters	**1.00**
Hydrodynamic Devices	**1.00**
Wetland Basins	**0.95**
Retention Ponds	**0.93**
Wetland Channels	**1.00**

Some of the other assessments that are being preformed are the potential reductions in toxicity of heavy metals by BMPs. More recent BMP studies have been collecting data on water hardness and therefore there is the ability to assess potential toxicity issues via comparisons of effluent quality with EPA acute and chronic criteria values (as benchmarks as the criteria apply in receiving waters). One trend that we have noticed in the data is that for many BMPs, hardness levels are increased in effluent versus the influent and therefore this could contribute along with concentration reductions to reduce toxicity (as defined by EPA's Acute Criteria for Aquatic Life). We will also be looking at the effects of BMPs on load reductions considering both hydrological source control performance as well as effluent quality.

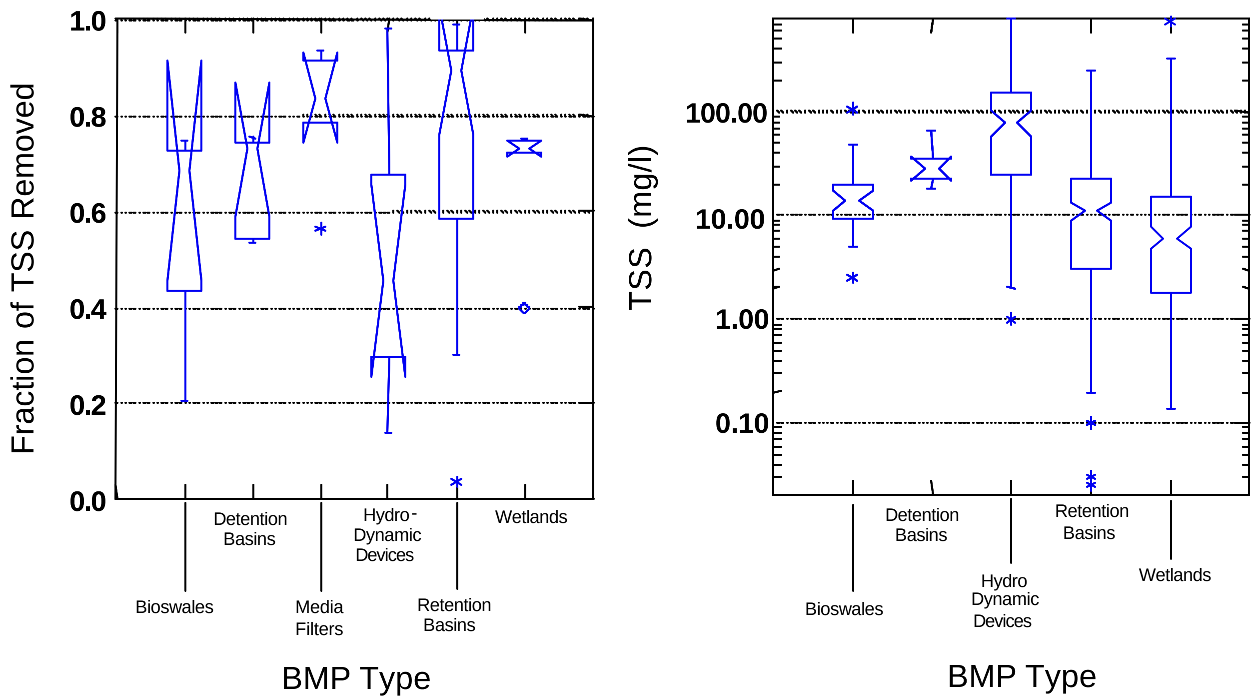

Figure 2. Box plots of the fractions of Total Suspended Solids (TSS) removed and of effluent quality of selected BMP types

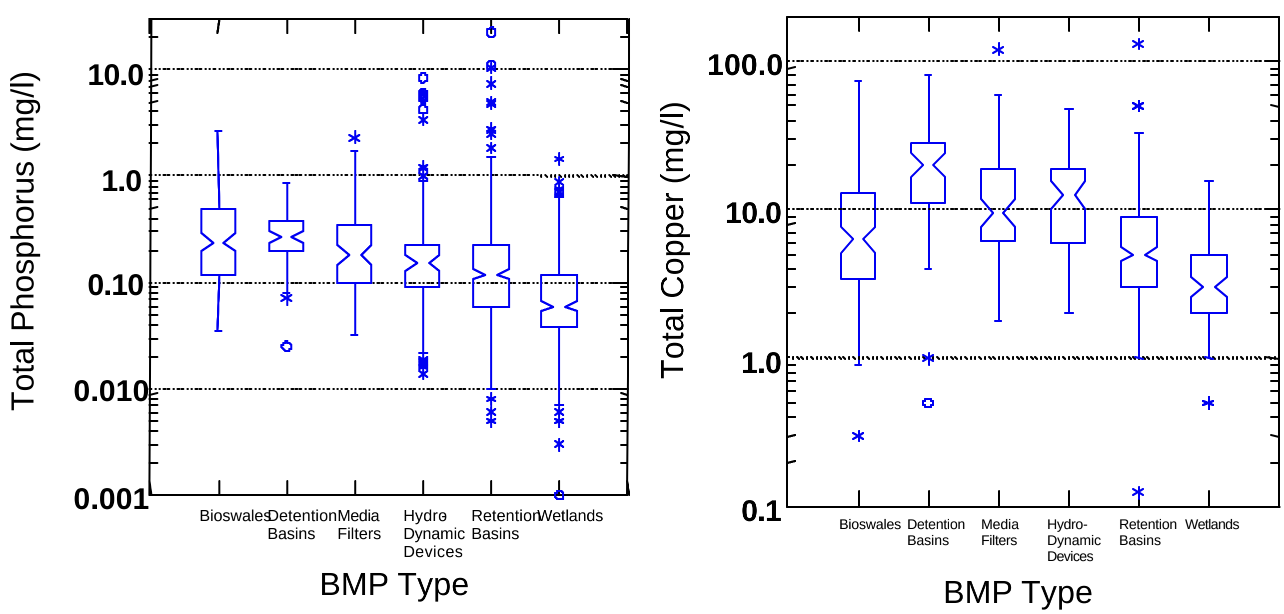

Figure 3. Box plots of effluent quality of selected BMP types for Total Phosphorus and Total Copper.

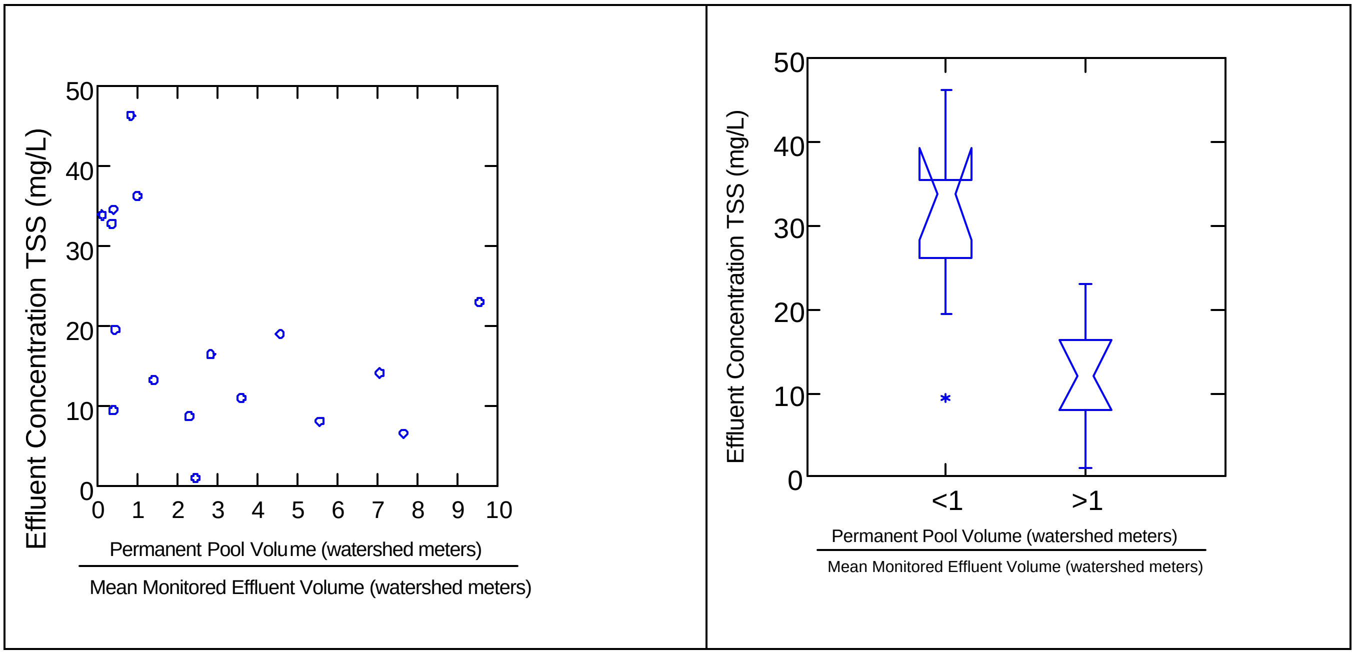

Figure 4. Scatter plot of 1) Retention Pond (with permanent wet pool) TSS effluent quality versus the ratio of the permanent pool volume to mean monitored effluent volume and 2) Box plots of the TSS effluent quality of sites grouped by a ratio of less than or greater than 1 for the ratio of the permanent pool volume to mean monitored effluent volume. (Note: watershed meters are calculated by dividing the volume by the total watershed area)

AN OVERVIEW OF THE URBAN STORMWATER BMP PERFORMANCE MONITORING

The Manual contains two main sections following the introduction:

Overview of BMP monitoring. A detailed discussion is provided on the context of BMP monitoring, difficulties in assessing BMP performance, and understanding the relationship between BMP study design and the attainment of monitoring program goals. Useful analysis of data collected from BMP monitoring studies is essential for understanding and comparing BMP monitoring study results. A summary of historical and recommended approaches for BMP performance data analysis is provided in this section to elucidate the relationship between the details and subtleties of each analysis approach and the assessment of performance. A recommended approach focusing on effluent quality and the amount of runoff treated (and not) is specified.

Developing and Implementing a Monitoring Program. This section provides specifics on how to develop a monitoring program, including selecting monitoring methods and equipment, installing and using equipment, implementing sampling approaches and techniques, and reporting information consistent with the National Stormwater Best Management Practices Database.

Supporting Materials. In addition, four appendices that focus on statistical methods for improving BMP monitoring studies and data reporting have been included in the guidance document. The first appendix describes detailed methods for estimating potential errors in field measurements. The second provides detailed information about the estimating the number of samples expected to be necessary to obtain statically significant monitoring data. The third appendix includes charts for estimating the number of samples required to observe a statically significant difference between two populations (e.g., inlet and outlet water quality) for a various levels of confidence and power. The final appendix is a table for estimating arithmetic descriptive statistics based on descriptive statistics of log-transformed data.

Understanding Variability and Sources of Error in BMP Performance Monitoring

Based on a review of existing studies, it is apparent that much BMP research in the past has not considered several key factors. The most frequently overlooked factor is the number of samples required to obtain statistically valid assessments of water quality. The Manual provides direct and applicable guidance on approaches to integrating quantitative evaluations of potential sample results variability to improve attainment of study goals via the collection of adequate data. As the National Stormwater Best Management Practices Database is founded on the quantitative assessment of water quality performance of BMPs, the Manual focuses on providing practitioners with firm statistical footing for study design and implementation within that context. Specifically the manual focuses on the four factors that influence the probability of identifying a significant temporal and/or spatial changes in water quality, including:

1) Overall variability in BMP influent and effluent water quality data.

2) Minimum detectable change in water quality (difference in the mean and variability of concentrations).

3) Number of influent and effluent samples collected.

4) Desired confidence level from which to draw conclusions.

The manual recommends that statistical analyses should be conducted to estimate how many events need to be monitored to achieve a specified level of confidence in a desired conclusion (i.e., power analysis). Performing a power analysis requires that the magnitude of acceptable error in effluent quality and/or detectable change in pollutant concentration, the confidence level, the estimated variability of future samples collected and the statistical power or probability of detecting a difference are defined or can be estimated. A complete set of nomographs provided by Pitt (2001) were included in the Manual.

In addition to drawing attention to the need to better integrate improved understanding of the inherent variability found in water quality data, the authors would like to emphasize the importance of collecting accurate flow data. Flow measurement data is often one of the most often overlooked sources of error and variability in BMP monitoring studies. In nearly all studies involving assessments of water quality, flow is used as a primary factor underlying all collected data. Not only are flow measurements used directly to calculate loads and event mean concentrations (depending on approach take), flows are often used to pace samplers for collection of flow-weighted samples. They are also used in an attempt to understand watershed hydrology and effects of BMPs on flow reduction and/or attenuation. Very few studies look quantitatively at the likely errors introduced into BMP performance studies as a result of flow measurement errors. Errors in flow measurements are most often caused by field conditions that are inconsistent with the conditions under which rating curves for flow devices were calibrated, improperly installed or selected equipment, or poor maintenance.

However, even under ideal conditions, errors in flow measurement can be significant. Quantitative analyses should be conducted to determine the likely errors associated with lower flow rates that in many climates result in the majority of total runoff volumes. Flow equipment should be designed to accurately quantify flows that may be orders of magnitude above and below the mean flow rate. This is particularly the case for very small watersheds (less than an acre) which have extremely peaky flows and are receiving increased monitoring attention with the growing installation of "in watershed" controls. Many flumes and depth measurement approaches which work for large watersheds do not function well when the flow rates rapidly vary by more than three orders of magnitude with extremely low flows occurring during light rainfall periods. It is recommended that primary devices be used where possible and their selection be made carefully with full knowledge of the magnitude of likely errors associated with the selection. For example in cases in which there is a need for measurement of extreme flow ranges and a free overflow (no backwater conditions exist down stream) is available, the H, HS, or HL flumes should be considered. The range of flows that can be measured relatively accurately using H-type flumes can exceed three orders of magnitude; for example, a 3 ft H flume can measure flows between 0.0347 cfs at 0.10 ft of head to 29.40 cfs at 2.95 feet of head. H flumes are also not prone to issues associated with sediment build-up and are relatively unaffected by upstream turbulence.

Weirs are generally recognized as more accurate than flumes (Grant and Dawson 1997). A properly installed weir can typically achieve accuracies within 2 to 5% of the actual rate of flow, while flumes can typically achieve accuracies of 3 to 10% (Spitzer 1996). The ASTM cites lower errors for weirs ranging from about 1 to 3% and Parshall and Palmer-Bowlus flumes with typical accuracies around 5%. However, the overall accuracy of the flow measurement system is dependant on a number of factors, including proper installation, proper location for head measurement, regular maintenance, sediment accumulation within storms, the accuracy of the method employed to measure the flow depth, approach velocities (weirs), and turbulence in the flow channel (flumes). It should be noted, however, that the largest source of error in flow measurement of stormwater results from inaccuracies related to low flow or unsteady flow. Improper construction, installation, or lack of maintenance can result in significant measurement errors. A silted weir or inaccurately constructed flume can have associated errors of ±5 to 10% or more (Grant and Dawson 1997). Circumstances present in many stormwater monitoring locations can result in errors well in excess of 100%.

There is a potential that certain BMPs could be more difficult to monitor accurately, as well as the outflow of some BMPs (those with significant storage) may be less peaky and therefore easier to measure. These both could affect the Qout/Qin (Table 2) results.

Other Sources of Error

A number of other sources of error are important to obtaining and reporting monitoring program data effectively. These errors should be specifically addressed in the QA/QC plan to increase awareness and potentially reduce their occurrence.

In many cases error is introduced in the process of transferring or interpreting information from the original data records. These errors most likely result from typographical errors or format and organizational problems. In most cases, water quality data are returned from the lab in some tabular format. Data are then entered into a database (or transferred from an electronic data deliverable-EDD), typically with separate records for each monitoring station and each storm event. Inconsistencies of data formats between monitoring events can considerably increase the potential for errors in entering data into the database and subsequently interpreting and using the processed (digital) data. Newly emerging tools for field data collection and observation such as personal digital assistant (PDA) deployed databases, which close the "paper gap" in collecting field data hold promise for decreasing some of the sources of these types of errors.

In addition to these "paper" errors, many other opportunities abound for introduction of other errors, including errors in interpretation and reporting of supporting information (e.g., misreading of maps, poor estimates of design, watershed, and environmental parameters, etc.) and reporting of information from previous studies that may have been originally incorrect.

In addition to the sources of error described above, all field collected and/or laboratory analyzed data on flow and water quality are subject to random variations that cannot be completely eliminated. These variations are defined as either "chance variations" or "assignable variations." Chance variations are due to the random nature of the parameters measured; increased testing efforts and accuracies cannot eliminate these variations. Although assignable variations cannot be eliminated altogether, these variations can be reduced and the reliability of the data increased. Assignable variations are those errors that result from measurement error, faulty machine settings, dirty containers, etc. As discussed previously in this paper, increasing both the length of a study and/or the number of storms sampled can reduce the assignable variations and increase the reliability of the data (Strecker 1992). Many monitoring studies take place over relatively short periods and have a small number of monitored storms during those periods. Thus the resultant data sets are often susceptible to both of these types of variations.

Data Analysis Methods

The ASCE/EPA project team reviewed available methodologies for data analysis as part of the publication of the first comprehensive analysis of data stored in the National Stormwater Best

Management Practices Database (available on the project website at www.bmpdatabase.org) and continues to look at more recent methods that have been proposed which are being used to re-evaluate the much more complete data set now available in the Database. In the manual, the authors recommend an effluent focused approach to efficiency evaluations labeled the Effluent Probability Method.

The Effluent Probability Method quantifies BMP efficiency in two steps. The first of these steps is to determine if the BMP is providing treatment (that the influent and effluent mean EMCs are statistically different from one another). The second step then focuses in on an examination of either a cumulative distribution function of influent and effluent quality or a standard parallel probability plot (essentially the same information in two different formats).

It is recommended that before any plots are generated, appropriate non-parametric (or if applicable parametric) statistical tests should be conducted to indicate if any perceived differences in influent and effluent mean event mean concentrations are statistically significant (the level of significance should be provided, instead of just noting if the result was significant, assume a 95% confidence level and 80% power).

The Effluent Probability Method is straightforward and directly provides a clear picture of one of the ultimate measures of BMP effectiveness, effluent water quality. Curves of this type may be the single most instructive piece of information that can result from a BMP evaluation study. Although an exact format has yet to be agreed upon, the authors of this paper strongly recommend that the stormwater industry accept this approach as a standard "rating curve" for BMP evaluation studies. An example in the recommended format is shown in Figure 5, alternately the y axis can include "percent less than" instead of the expected value of the standardized normal distribution. It is critical that the BMP study also report on how much of the runoff is actually treated versus bypassed as well as infiltrated or evapotranspirated as appropriate for some BMPs. This is the hydraulic performance of the BMP and effects evaluation of the effectiveness of various BMP sizes.

The Urban Water Resources Research Council and the Co-Principal Investigators for the ASCE/EPA National Stormwater Best Management Practices Database at the time of the writing of the paper are in the process of recommending a final format or standard "cut sheet" that will be recommended for inclusion in any BMP monitoring study to clearly and succinctly provide vital information to practitioners on the performance of a particular BMP. This standard "cut sheet" will be posted on the project website (www.bmpbatabase.org) both in generic format with guidelines for use and will be created for each BMP study that is included in the National Database.

Selecting Parameters

Stormwater runoff may contain a variety of substances that can adversely affect the beneficial uses of receiving water bodies. The Manual recommends that the following factors are important to examine when selecting parameters to be included in a BMP monitoring program:

- Permit requirements (if any). Monitoring to comply with a permit may specify the parameters that must be measured in stormwater discharges. However, monitoring for additional parameters may help attain overall program objectives.

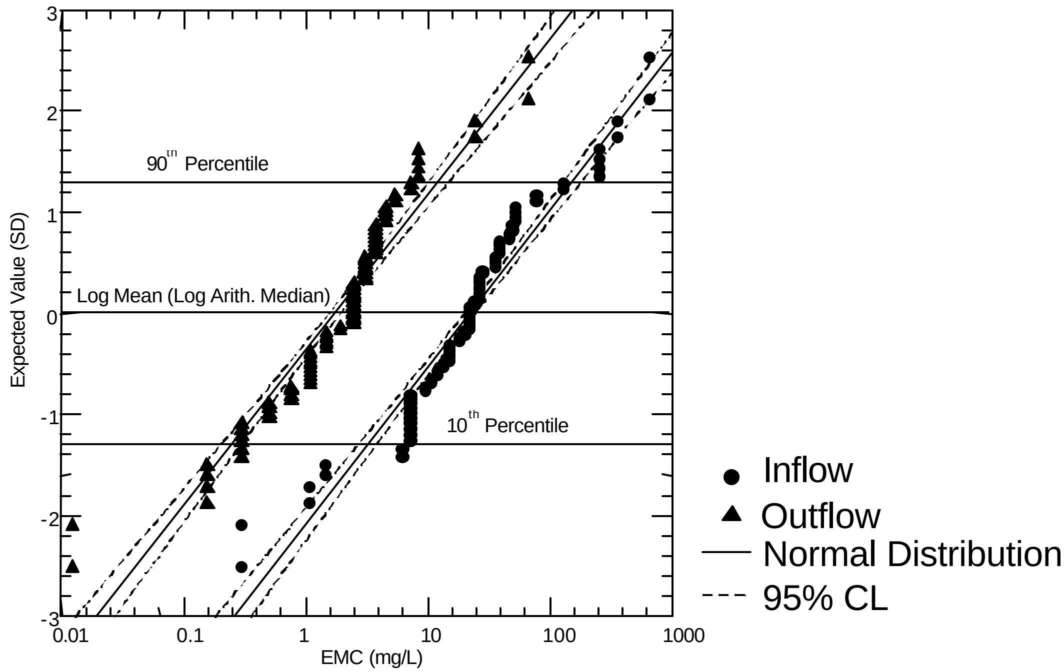

Figure 5. Example Normal Probability Plot Recommended for Inclusion in All BMP Monitoring Studies as Part of the Effluent Probability Method.

- Land uses in the catchment area. Land use is a major factor affecting stormwater quality. Developing a list of the pollutants commonly associated with various land uses is helpful for deciding what to look for when monitoring.

- Existing monitoring data (if any) for the catchment area. Previous monitoring data can be helpful in refining the parameter list and developing estimates of the potential variability of the BMP influent data. However, if there is uncertainty about the monitoring methods and/or analytical data quality, or if the existing data pertain to baseflow conditions or only one or two storms, caution should be used in ruling out potential pollutants. For example, an earlier study may have used outdated analytical methods which had higher detection limits than current methods.

- Beneficial uses of the receiving water. Information on water quality within a stormwater drainage system often is used to indicate whether discharges from the system are likely to adversely affect the receiving water body. For example, if a stormwater system discharges to a lake, consider analyzing for nitrogen and phosphorus because those constituents may promote eutrophication.

- Overall program objectives and resources. The parameter list should be adjusted to match resources (personnel, funds, time). If program objectives require assessing a large number of parameters (based on a review of land uses, prior monitoring data, etc.), consider a screening approach where samples collected during the first one or two storms are analyzed for a broad range of parameters of potential concern. Parameters that are not detected, or are measured at levels well below concern, can then be dropped from some or all subsequent monitoring events. To increase the probability of detecting the full range of pollutants, the initial screening samples should be collected from storms that occur after prolonged dry periods.

A recommended list of constituents (along with recommended method detection limits for comparing stormwater samples to water quality criteria) for BMP monitoring has been developed and is presented in Table 3 below. Refer to Strecker (1994) and Urbonas (1994) for more information on BMP monitoring parameters. The choice of which constituents to include as standard parameters is subjective. The following factors were considered in developing the recommended list of monitoring parameters:

- The pollutant has been identified as prevalent in typical urban stormwater at concentrations that could cause water quality impairment (NURP 1983; FHWA 1990; and recent Municipal NPDES data).
- The analytical result can be related back to potential water quality impairment.
- Sampling methods for the pollutant are straightforward and reliable for a moderately careful investigator.
- Analysis of the pollutant is economical on a widespread basis.
- Controlling the pollutant through practical BMPs, rather than trying to eliminate the source of the pollutant (e.g., treating to remove pesticide downstream instead of eliminating pesticide use).

Although not all of the pollutants recommended here fully meet all of the factors listed above, the factors were considered in making the recommendations. When developing a list of parameters to monitor for a given BMP evaluation, it is important to consider the upstream land uses and activities.

The base list represents a basic set of parameters. There may be appropriate applications where other parameters should be included. For a discussion of why some parameters were not included, see Strecker (1994).

Dissolved versus Total Metals

Different metal forms (species) show different levels of toxic effects. In general, metals are most toxic in their dissolved, or free ionic form. Specifically, EPA developed revised criteria for the following dissolved metals: arsenic, cadmium, chromium, copper, lead, mercury (acute only), nickel, silver, and zinc. Chronic criteria for dissolved mercury were not proposed because the criteria were developed based on mercury residuals in aquatic organisms (food chain effects) rather than based on toxicity. For comparisons with water quality criteria, it is advised that the dissolved metals fraction be determined, along with total metals. If selenium or mercury is of concern, total concentrations should be measured to enable comparison with criteria based on bioaccumulation by organisms.

Table 3: Typical urban stormwater runoff constituents and recommended detection limits

Parameter	Units	Target Detection Limit
Conventional		
pH	pH	N/A
Turbidity	mg/L	4
Total Suspended Solids	mg/L	4
Total Hardness	mg/L	5
Chloride	mg/L	1
Bacteria		
Fecal Coliform	MPN/100ml	2
Total Coliform	MPN/100ml	2
Enterococci	MPN/100ml	2
Nutrients		
Orthophosphate	mg/L	0.05
Phosphorus – Total	mg/L	0.05
Total Kjeldahl Nitrogen (TKN)	mg/L	0.3
Nitrate – N	mg/L	0.1
Metals-Total Recoverable		
Total Recoverable Digestion	µg/L	0.2
Cadmium	µg/L	1
Copper	µg/L	1
Lead	µg/L	5
Zinc		
Metals-Dissolved		
Filtration/Digestion	µg/L	0.2
Cadmium	µg/L	1
Copper	µg/L	1
Lead	µg/L	5
Zinc		
Organics		
Organophosphate Pesticides (scan)	µg/L	0.05 - .2

Note: This list includes constituents found in typical urban stormwater runoff. Additional parameters may be needed to address site specific concerns.

The distribution of pollutants between the dissolved and particulate phases will depend on where in the system the sample is collected. Runoff collected in pipes with little sediment and organic matter will generally have a higher percentage of pollutants present in the dissolved form. Runoff collected in receiving waters will generally have a higher percentage of pollutants present in particulate form due to higher concentrations of suspended solids and organic matter that acts as adsorption sites for pollutants to attach to. It is difficult to determine how much of the dissolved pollutants found in storm system pipes will remain in the dissolved form when they are mixed with suspended sediments in receiving waters. As a result, it is difficult to determine the ecological significance of moderate levels of dissolved pollutants present within the conveyance system. In addition, hardness values for receiving waters are often different than those for stormwater. Hardness affects the bio-availability of heavy metals, further complicating the ecological impact of dissolved heavy metals. Hardness values are typically higher in hardened conveyance systems that in receiving waters or earthen channels.

If loads to the receiving waters are of concern (e.g., discharge to a lake known to be a water quality limited water body) than analyzing for total recoverable metals is particularly recommended. Finally, total recoverable metals data together with dissolved metals data can be used to assess potential metals sediment issues.

Measurements of Sediment Concentration

A variety of methods have been employed in stormwater quality studies for quantifying sediment concentrations. The most frequently cited parameter is "TSS" or total suspended solids. The "TSS" label is used, however, to refer to more than one sample collection and sample analysis method. The "TSS" analytical method originated in wastewater analysis as promulgated by the American Public Health Association.

The USGS employs the suspended-sediment concentration (SSC) method (ASTM 2000), which was originally developed for the Federal Interagency Sedimentation Project (USGS 2001). SSC data is often described as TSS data, when in many cases results from the two methods can be significantly different. The difference between methods is sample size – the SSC method analyzes the entire sample while the TSS method uses a sub-sample. The process of collecting a representative sub-sample containing larger sediment particles is problematic as large sediment particles (e.g., sand) often settle very quickly. Differences between the results obtained from SSC and TSS analytical methods become apparent when sand-sized particles exceed 25% of the sample sediment mass (Gray et al. 2000). Gray demonstrates that at similar flow rates, sediment discharge values from SSC data can be more than an order of magnitude larger than those from TSS data (USGS 2001) due primarily to larger particles that are often missed in the TSS method. "The USGS policy on the collection and use of TSS data establishes that TSS concentrations and resulting load calculations of suspended material in water samples collected from open channel flow are not appropriate" (USGS 2001).

The authors recommend that both TSS (for comparison to existing data sets) and SSC be measured for BMP monitoring studies. The difference between TSS and SSC in samples from BMPs that are even mildly performing should be minimal (e.g., if the BMP is functioning at all then the sands and larger particles should be removed. Therefore, assessing effluent data from past BMP performance studies, rather than percent removal eliminates, is likely to be a much more valid approach.

The discrepancies in sampling methodologies currently employed in the field highlight the importance of particle size distribution (PSD) analysis as an essential component of any BMP monitoring study. PSD data provide the information necessary to meaningfully interpret the ability of a BMP to remove suspended materials. However, PSD methods are varied even within a given technique and include (USGS 2001):

- Dry sieve.
- Wet sieve.
- Visual accumulation tube (VA).
- Bottom withdrawal tube.
- Pipet.
- Microscopy.
- Coulter counter.
- Sedigraph (x-ray sedimentation).
- Brinkman particle size analyzer.
- Laser diffraction spectroscopy.
- Light-based image analysis

At this time the authors recommend selecting and using a consistent and appropriate method from the above (i.e., no single method has been established as the standard).

Specific gravity (SG) of sediments is also an important component in determining the settleability of sediments and is recommended for sediment analysis by ASTM (1997). For BMP studies where PSD data are being collected, SG provides additional useful information about the ability of a particular BMP to remove sediment.

In addition, settling velocities of sediments are highly important and can be either measured directly or calculated theoretically from SG and PSD data. Settling velocities give the most useful information for quantifying BMP sediment removal efficiency.

The difficulty of collecting accurate sediment samples underscores the need to fully understand the conditions under which sediment data were collected and analyzed. Regardless of the analytical methods used, the sampling methodology often introduces the largest bias to sediment data. For example the depth at which the sample was collected can significantly impact results. Again, the impacts would be much greater on influent data rather than effluent data due to the fact the BMP should be removing the larger particles.

CONCLUSIONS

An evolving tool is available to practitioners who are assessing the performance of BMPs via the National Stormwater Best Management Practices Database Project. Practitioners can perform their own evaluations by downloading information from the web site.

Results of the analyses of the now expanded database have reinforced the initial finding that BMPs are best described by how much they reduce runoff volumes, how much of the runoff that occurs is treated (and not) by the BMP, and of the runoff treated what effluent quality (concentrations and potential toxicity) is achieved. These basic BMP performance descriptions can then be utilized to assess effects on total loadings, frequency of potential exceedances of water quality criteria or other targets, and other desired water quality performance measures. The results show that the effluent quality of various BMP types can be statistically characterized as being different from one another. Additionally, some design parameters may be statistically significant with regards to performance.

A new guidance tool is available to practitioners who are conducting BMP monitoring studies and wish to comply with the standards established as part of the National Stormwater Best Management Practices Database Project. The Manual contains a comprehensive and practical discussion on all elements of water quality, flow, and precipitation monitoring and discusses them within the specific framework of the National Database.

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